Magnetic domain structure in multilayers containing metallic antiferromagnets

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INTRODUCTION

The magnetic structure of antiferro- and ferromagnetic materials is a very active field of research because of applications in magnetic data storage. Antiferromagnetic layers are an important component of hard disk read heads and of non-volatile magnetic random access memory elements, MRAM. The effect of exchange bias at the interface between an antiferromagnetic (AFM) and a ferromagnetic (FM) layer expresses itself as a unidirectional pinning or anisotropy of the magnetization of the ferromagnet, and is utilized to fix the magnetization in a magnetic reference layer in a spin-valve structure or a magnetic tunnel junction (MTJ), which consists of two ferromagnetic layers separated by a non-magnetic metal (spin-valve) or an insulator (MTJ). Initially, oxide antiferromagnets were used in exchange bias applications but presently metallic alloys of manganese and other transitions metals such as Fe, Ni, Pt or Ir are used because of their larger bias and better stability.

RESULTS

Here we will report recent results on exchange coupling across manganese antiferromagnets, in particular Mn and FeMn thin films. A NiO (001) single crystal was used as substrate material. The crystal was cleaved ex-situ and then prepared by Ar sputtering and subsequent extensive annealing at 800 K in O_2 atmosphere ($1x10^{-6}$ mbar, several hours). LEED images showed a well-ordered surface of cubic symmetry. The same crystal could be reused many times. The ALS PEEM-2 Photoemission Electron Microscope was used to obtain local x-ray absorption spectra and magnetic domain images with magnetic linear and circular dichroism contrast [1,2].

FeMn layers were grown by electron beam evaporation from element sources. The sources were calibrated using a thickness monitor to equal flux in order to grow films of approximately $Fe_{0.5}Mn_{0.5}$ composition. The overview x-ray absorption spectrum in Fig. 1 acquired at low spatial resolution using PEEM shows approximately equal edge jumps at the Mn and Fe edges. The

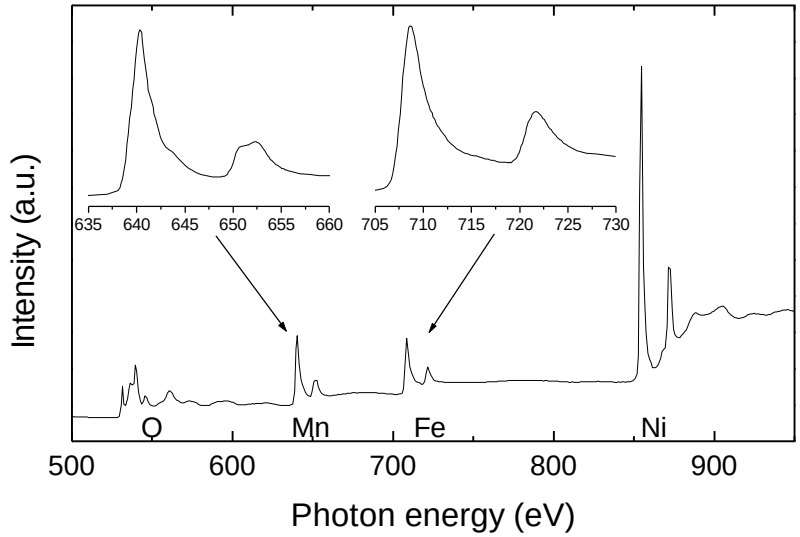

Fig. 1: X-ray absorption spectrum of 13 Å FeMn/NiO acquired by PEEM. The insets show higher resolution spectra of the Mn and Fe edges.

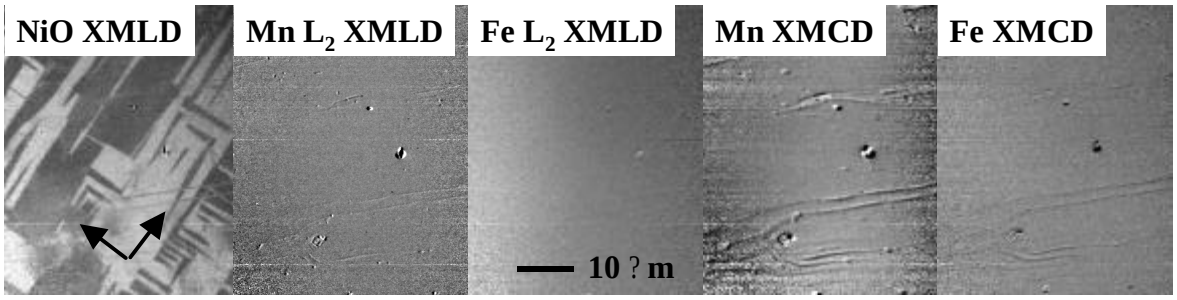

Fig. 2: X-ray magnetic dichroism images of 13 Å FeMn/NiO. Arrows mark the [100] and [010] directions

strong O and Ni signal originates from the NiO substrate. The Mn and Fe edges show the characteristic shapes known for metallic Mn and Fe. In particular, the multiplet structure in the Mn L_3 and L_2 resonance is resolved. No strong oxidization of the FeMn layer is visible in the spectra, which would result in a change of the Fe and Mn line shape.

PEEM magnetic dichroism images using linearly and circularly polarized x-rays show the magnetic domain structure of the NiO substrate and the FeMn thin film, Fig.2. The XMLD image of NiO acquired at the L_2 edge shows the expected domain structure with AFM axes along [110] (vertical, dark color) and [1-10] (horizontal, bright color). Domain walls form along [100] and [010]. The XMLD images acquired at the Mn L_2 edge (see Fig. 1) and at the Fe L_2 edge do not show any discernible contrast within our sensitivity, setting an upper limit for the XMLD contrast in FeMn to 1%. The XMLD contrast in FeMn is therefore much lower as in oxide AFMs, such as NiO or $LaFeO_3$, and thus much more difficult to detect. The non-existent ferromagnetic domain contrast in the Fe and Mn circular dichroism images furthermore proves the non-ferromagnetic, AFM character of the FeMn film. The remaining structure in the images (lines, dots) originates from topography, which is not completely suppressed in the dichroism images.

After growth of 14 Å of pure Fe ferromagnetic domains become visible in the Fe dichroism image. The domain pattern is correlated to the domain pattern in the AFM NiO substrate, Fig.3. The magnetic axes in Fe and NiO couple parallel, indictating a strong uniaxial exchange anisotropy transferred by an AFM FeMn interlayer. For example, black and white domains in the Fe layer belong to domains with a magnetization pointing down or up, respectively. These domains are always located in regions which appear in a dark gray tone in the XMLD image of the buried NiO antiferromagnet and possess a AFM axis which is vertical. The uniaxial coupling across FeMn implies that the magnetic structure in the spacer is similar to the structure in the NiO layer. No correlation should appear if the magnetic structure in the FeMn layer were completely unrelated. Assuming a parallel coupling at the NiO/FeMn interface we deduce that the coupling at the FeMn/Fe interface is parallel as well. These measurements demonstrate how PEEM provides information about the magnetic structure of the metallic AFM interlayer although the domain

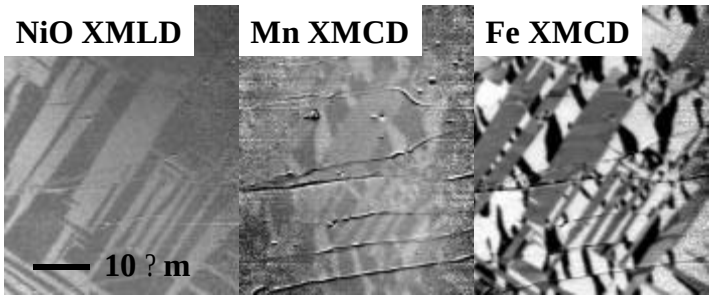

Fig. 3: X-ray magnetic dichroism images of 14 Å Fe/13 Å FeMn/NiO

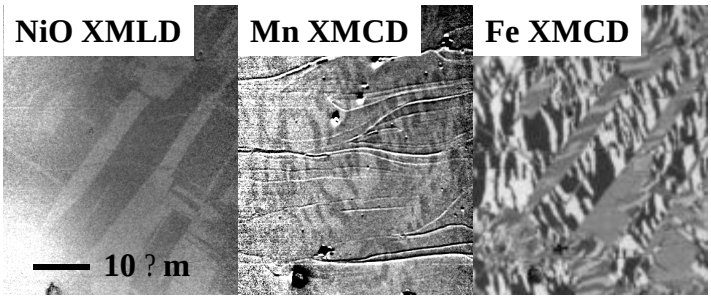

Fig. 4: X-ray magnetic dichroism images of 7 Å Fe/7 Å Mn/NiO

structure is not directly resolved. The XMCD image of Mn in the FeMn layer shows a weak domain contrast which resembles the domain structure in the Fe overlayer, although with opposite sign. Because no contrast was apparent in the Mn XMCD images prior to the growth of pure Fe, we deduce that the appearing contrast is either due to a ferromagnetic polarization of the interface layer, or a chemical reaction at the interface, changing the composition of the interface, a mechanism similar to one observed at oxide-metal interfaces. The inverted contrast shows that Fe and Mn couple antiferromagnetically in the studied sample, a problem that has been discussed controversially in the literature. A possible ferromagnetic moment of the Fe component in the FeMn layer could not be studied because of the large FM signal of the pure Fe layer on top.

A similar behavior was observed in case of pure Mn interlayers. Fig. 4 shows domain images of a 7 Å Fe/8 Å Mn/NiO structure. We again observe a correlation of the magnetic domain patterns across the AFM interlayer. We furthermore observe a ferromagnetic Mn moment. The domain contrast is inverted, demonstrating an antiferromagnetic interface coupling between Fe and Mn. The less regular domain structure in the Fe layer and the appearance of brightness variations within ferromagnetic domains furthermore indicates a weaker coupling across the Mn spacer than across FeMn.

REFERENCES

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